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THE MEASUREMENT OF MAN-HELICOPTER PERFORMANCE AS A FUNCTION OF EXTENDED FLIGHT REQUIREMENTS AND AVIATOR FATIGUE

Final Report

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20. ABSTRACT

Field commanders have long been concerned about the impact of fatigue on aviator effectiveness, especially where aviators are called upon to fly numerous successive stress-related missions (e.g., combat and/or rescue work). At present there is little specific information upon which the commander can base his crew rest decisions. The US Army Aeromedical Research Laboratory sought to answer this need by observing pilots in an actual flight situation. In this study six pilots flew a helicopter for 11 1/2 hours per day for 5 days with 3.5 hours of sleep per day. Data collection included biochemical, visual, psychological and in-flight measurements. This report includes a critical literature review and describes the methodology of the study. It is intended to serve as a detailed background for the analyses to follow.

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Our special thanks go to Mrs. Betty Dyess, DAC, who spent many hours typing the manuscript.

Dr. Michael A. Lees is no longer with the laboratory. He is currently heading a family business in Rapid City, South Dakota.

Dr. David B. Anderson is now in a consultant status. His present position is Assistant Professor of Animal Science College of Agriculture, Department of Animal Science, 124 Animal Sciences Laboratory, Urbana, Illinois.

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INTRODUCTION

The detrimental impact of fatigue on aircrew effectiveness has long been an area of concern for the flight commander. This concern has increased as the workload of the aircrew has been enlarged to satisfy the modern tactical requirements of:

1. Around-the-clock operations.[1,2]

2. Flight profiles which capitalize on terrain masking.[3]

3. Avoidance of the intensive antiaircraft threat.[4]

4. The operation of sophisticated equipment[5] in addition to normal flight duties.

In addition to his normal concern for the aviator's welfare and the effective utilization of his aviation resources, the local flight commander now has the responsibility under US Army regulation (AR 95-1, Chapter 5, Para 5-9 and Table 5-1)[6] to establish flight time limitations and crew rest requirements for those aviators under his command. At the current time the local flight commander has little specific information at his disposal to assist him in fulfilling this responsibility. Not only is there a noticeable lack of guidelines for evaluating the effects of fatigue and extended flight requirements on different aircraft missions; but, also, there is no available method of obtaining a practical measurement of an aircrew's current fatigue level and suitability for future missions. This type of information is essential if the local commander is to make informed judgments on the current level of aircrew fatigue and the probability of mission accomplishment.

The US Army Aeromedical Research Laboratory (USAARL) has long recognized the impact of aviator fatigue on the well-being of the soldier as well as the potential impact on the aviation mission.[7-13] USAARL developed an extensive fatigue research program in a scientific effort to provide relevant information to the flight commanders. One phase of this investigation consisted of an extensive field study which examined the effects of extended flight requirements on aviator fatigue and performance. Because of the magnitude of this investigation, the analytical results will be presented in several stages. The purpose of the current report is to provide a thorough description of the fatigue investigation to be used as the background for the more specific descriptions that accompany each technical report.

The goal of this field investigation was to identify a practical method of measuring aircrew fatigue. Thus, the USAARL research team investigated biochemical, physiological, and psychological parameters in conjunction with measures of man-helicopter system performance during a period of exhaustive flight activity. This fatigue study was conducted over a 6-week period and examined a total of six experimental subjects to identify an objective measure of aircrew fatigue, particularly pilot fatigue, that could be readily used in the field environment. This fatigue measure would also be compared to direct measure of helicopter performance and, thus, provide the flight commander with the specific fatigue information that he requires.

The current report first presents an examination of previous literature that is relevant in describing the effects of aircrew fatigue. It identifies several information gaps that must be filled to provide relevant information to the flight commander. The critical review is followed by a description of the USAARL fatigue study. This includes a presentation of the experimental schedules and a description of the investigation procedures. The current report presents a thorough description of the information reduction process required to prepare the in-flight man-helicopter system performance data for analysis.

CRITICAL REVIEW OF THE LITERATURE

The overall goal of the USAARL fatigue research program is to provide the flight commanders and other decision makers with practical information on which to base mission judgments. One ongoing portion of the USAARL fatigue research program consists of reviewing the fatigue related research literature to extract relevant information. It quickly becomes apparent that a great deal of previous research has examined physiological changes in humans and their performance resulting from some form of fatigue.[14-18] It also becomes apparent that this research is presented under a wide variety of labels, including fatigue studies, sleep loss or sleep deprivation investigations, examinations of work/rest cycles, performance during extended operations, and others. Several authors[19 20] have noted the confusion that has been caused using the term "fatigue" to mean different things. Within the current report and those future reports describing the field investigation, fatigue is considered to be the result of the extended flight requirements. In this sense, the concept of fatigue cannot be considered apart from its inherent components which include changes in the ability of the man to control the helicopter, the subjective feelings of "fatigue" that were reported by the subjects, the changes in "mood and alertness," and the changes in the physiological state of the subject.

This operational definition of the term fatigue fits appropriately under a more general area of research; that is, "operator workload."

"Workload" is another term with many definitions that vary between authors; however, one definition of the workload research area presented by Jahns[21] seems particularly useful. Basically, Jahns has suggested that workload, including the effects of such factors as fatigue, is not a unidimensional measurement, and that to provide meaningful quantitative answers regarding workload "we must begin to look at and handle the overall integrated complexity of man-machine environment systems." In adopting a practical approach to handling the relevant workload variables, Jahns has suggested dividing the broad area of operator workload into three functionally relatable attributes:

1. Input including the environmental, situational and procedural inputs.

2. Operator effort which is operationally defined as the proportion of processing capacity used to meet the processing requirements.

3. "Work result" generated through the effort exerted by the human operator, which serves as input to other components of the man-machine environment system and provides feedback on effort adequacy.

An advantage of viewing fatigue as only one of many factors that can impact the man-machine system performance is that it allows one to examine previous research and determine which of the relevant factors affecting the operator's workload have been addressed. This point of view provides a reasonably standard frame of reference for examining research results and subsequently determining if this research offers practical guidelines for operational questions concerning specific man-machine systems. For example, during the USAARL field investigation described in this report the goal was to measure the level of pilot "fatigue" and determine the effect on the man-helicopter system performance. To induce this fatigue, the pilots were required to operate under an extended flight schedule. This report demonstrates that from a system point of view many aspects that could affect operator workload, such as the type of aircraft and the type of mission, were held constant during the investigation. Other aspects of the system that affect workload such as weather, wind, and the illumination level could not be controlled, but were measured to provide statistical control of their effects on performance. Using the man-helicopter system point of view, the results from this investigation and the results from previous studies can be examined to determine practical guidelines for flight planning purposes.

In seeking to provide practical information to aviation resource managers another point of contention within the field of workload research becomes evident. There appears to be a lively international debate concerning the appropriate measure of workload. In many cases the type of information that is required and the degree of system completion (i.e., fully operational systems vs paper design) effectively determine the appropriate measure of workload for that system. However, when examining complex systems such as the helicopter, some authors[22] suggest that a workload measure that concentrates on operator effort is preferable to a measure of system performance. Given the emphasis on providing practical information to aviation commanders, it is imperative that the man-helicopter system performance be considered as being of primary importance. For this investigation, measures of effort both from a psychomotor and physiological viewpoint are also regarded as important measures reflecting the fatigue-related changes in man-helicopter system performance.

During an extensive review of the performance and fatigue literature, investigations were divided into three categories on the basis of the types of fatigue measures that were employed:

1. Subjective measures of an individual's ability, readiness or performance obtained either from the individual himself or from some "expert judgment source."

2. Measurements of changes in the biochemical or physiological status of the individual as a result of fatigue and its antecedent conditions.

3. Measurement of changes in the individual's task performance either in the time to complete the task, the number of tasks completed or the error produced during a continuous task.

In an effort to more clearly present the relevant information, these three categories of fatigue research were further divided into those studies that were conducted in a laboratory setting (or in a nonaviation field environment) and those studies that were directly linked to some aspect of aviation.

LABORATORY RESEARCH

Previous laboratory research on continuous operations, sleep loss and fatigue has shown a wide variety of effects on performance tasks from no effect to a complete breakdown in measured performance. Most early lab studies failed to discover predictable and consistently detrimental effects as a result of extended sleep loss. The only reliable changes obtained from this area of research were in the subjective ratings of mood and in the appearance of the subjects.[14] Major refinements in the methods of examining performance data were necessary before research investigations on sleep deprivation were able to produce consistent and replicative results.

Early approaches in the fatigue research areas emphasized the measurement of changes in the accuracy of the man's performance. This method of examination was not consistent in obtaining repeatable fatigue effects. As a result of these shortcomings, a new approach was developed in which the man's performance was examined to identify those periods where there was an absence or pause in measured responses. Much of this early work and development of a more consistent research methodology can be credited to the research programs at Walter Reed Army Institute of Research (WRAIR). Bills,[23] in studying mental task performance, found that the frequency and duration of those time blocks where the subject's responses were reduced, increased with fatigue, and that errors tended to occur in conjunction with these lapses of response. Bills suggested that these lapses were involuntary rest periods which delayed the onset of major fatigue effects. Bjerner[24] showed physiological indications of sleep occurring when these lapses were observed in a reaction time task. In addition to these investigations, researchers at WRAIR conducted a series of studies to evaluate various laboratory tasks for sensitivity to sleep loss. From these studies[25] they developed four points regarding the WRAIR lapse hypothesis:

1. Sleep-deprived subjects show brief intermittent lapses in response, and these lapses increased in frequency and duration as the hours of sleep loss increased.

2. Certain factors in a test situation tend to alert the subject, thus preventing or shortening the lapses. These include massive sensory stimulation such as physical exercise or shock, feedback on performance quality, or change in task.

3. Overlearned task or automatic response sequence is relatively resistent to sleep loss.

4. Many, but not all, tasks will be affected by diurnal rhythm influences on sleep loss and will show greater performance change during the early morning hours.

Although the lapse hypothesis explained most laboratory performance decrements following sleep loss, especially in vigilance or motor performance laboratory tasks,[14] it did not adequately describe memory performance decrement. In investigations of immediate recall of word lists, it was determined that sleep loss caused difficulties in the formulation of the memory trace.[25] Other authors[26] prefer to emphasize change in information processing capability rather than lapses or periods of microsleep.

In an effort to provide results that can be better generalized to operational situations, several investigators have examined sustained performance on a variety of performance tasks. Drucker [and others][27] studied enlisted tank crewmen to determine the effects of total sleep loss incurred during 48 hours of continuous operation on simulated driving and target recognition tasks. This study showed substantial decrements in driving and target recognition during the second night. The authors concluded that there was a substantial influence of the circadian cycle during the second night. They suggest that there was relatively little gain in total productivity as a result of working for 48 hours without sleep as compared to working shorter periods with time off for sleep. They found that job rotation helped to improve the task performance slightly, but that this was not sufficient to overcome the sleep loss effects seen during night performance. Drucker and his associates suggest that fatigue could be reduced by limiting continuous performance to a range of from 36 to 40 hours if the continuous performance is started in the morning.

Morgan, Alluisi and their associates[28 29] have examined a wide range of sustained performance schedules using the Multiple Task Performance Battery. From these investigations,[28] they found that even though performance did not always follow the diurnal cycle during normal work periods, it was likely to do so during periods of continuous operations. During 48 hours of continuous operations, subjects were able to maintain their performance near 100% of baseline for approximately 18 hours. Performance then dropped to nearly 81% of baseline during the last 8 hours of the first 24-hour period. This point of degraded performance coincided with the end of the first night. On the second day, performance improved to above 80% of baseline and then hit a low point of about 67% of baseline during the second night. These findings suggest that the accuracy of performance is an effective measure of fatigue when used in a more realistic simulation of complex work environments.

The differential effect of age and experience in adapting to fatigue was demonstrated by an investigation[30] that examined electronic rifle firing by young officers and corporals, and for senior officers during 72 hours of continuous operations. Both age groups showed fairly standard increases in fatigue levels, particularly at night. The peak fatigue level for the third night was similar to that seen during the second night and the authors have suggested a flattening of the fatigue level after it has reached its maximum value. A finding of interest was that the senior officers did not show performance decrements in the rifle-firing task.

Those investigators who have examined operational performance in the field generally have not found the same performance decrements demonstrated in similar laboratory research. When Haggard[31] attempted to replicate the study on sleep loss effects on tank driving performance,[27] he found no performance decrements that could be attributed to fatigue after 48 hours of continuous operations. Haggard concluded, "It would appear that the usual laboratory situation requiring continuous performance of a single task does not sufficiently duplicate the job situation where many tasks must be performed--any one of which occurs only periodically. Thus we might well question the continuing use of standard tasks, in present laboratory situations, to predict job performance in real life situations."

In their outstanding review of previous laboratory fatigue research, Johnson and Naitoh[14] have identified seven general factors which influence the effect of sleep loss on man's performance:

1. Task duration. The longer the task the more sensitive it is to total sleep loss.

2. Knowledge of results. Immediate feedback on the quality of performance minimizes the effects of total sleep loss.

3. Difficulty of task. Performance on difficult tasks is more sensitive to sleep loss.

4. Task pacing. Work on self-paced tasks resists sleep loss effects much better than work on forced-pace tasks.

5. Proficiency in task performance. Previous research has indicated that newly acquired skills are more affected by loss of total sleep than those skills, particularly motor skills, which have become almost automatic or highly overlearned.

6. Task complexity. The more complex the task, with respect to a sequence of mental operations and/or the execution of complex muscular activities, the more likely it is to be sensitive to sleep loss.

7. Memory requirements. Any task which requires a short-term memory chain will be affected by sleep loss.

In addition to these task related factors, Johnson and Naitoh[14] have pointed out that other factors such as high interest in the job, or high motivation, can lessen the performance decrements observed during long-term operations. The influence of circadian or diurnal rhythms has been observed in most of the sustained performance research and it has been shown that repeated exposures to total sleep loss increases the effect on task performance.

Even though the results from this massive quantity of previous laboratory and field research are not always consistent or conclusive, there are two positive findings that are applicable to developing flight planning guidelines:

1. The influence of the circadian rhythm on tasks performed during sustained operations has been repeatedly demonstrated. An inevitable result of sustained operations is the disruption of the normal sleep/wake cycle and the requirement to perform during periods of low metabolic activity. Thus, any prediction of man's ability to perform must take these interrelated factors of diurnal rhythm and sleep/wake cycle disruption into account.

2. Previous research has produced evidence to determine what type of change in performance will occur; that is, lapses in the performance or changes in information processing rates. This research has also shown that performance decrements will usually appear after about 18 hours of continuous operations and again after about 48 hours, particularly if these time periods occur at night during the normal diurnal low period.

However, there are several major drawbacks in attempting to use the results from previous laboratory and field research in specifying the effects of fatigue in an operational environment. It is extremely difficult to generalize from this type of highly controlled and artificial research to the actual field environment of the aircrew. Previous attempts to replicate laboratory research in the field environment have shown that lab tasks do not adequately represent the complexity or diversity of the real world. It has often been observed that many of the sustained laboratory tasks are boring and monotonous and certainly lack the responsibility and motivation evident in the operational flight environment. The laboratory situation, which usually includes a well-defined and controlled task, also limits the flexibility of the operator in developing adaptive strategies or techniques to accomplish the mission.

AVIATION RESEARCH

As early as 1951, there was a well-defined interest in the effects of fatigue on the aviator. Bartlett[32] utilized the findings from aircrew simulation research and other investigations to develop his concept of skill fatigue. Bartlett felt that this skill fatigue was the major factor in aviator performance changes. He felt there were four consequences of this skill fatigue:

1. A deterioration in the accuracy of timing the components of the skilled tasks with a decrease in the level of skill.

2. Pilots accept a lower standard of accuracy and performance without an appreciation that they are doing so.

3. There is a disintegration of the perceptual field so that readings from individual instruments are no longer integrated into an overall pattern.

4. The pilot's range of attention is narrowed so that some instruments or tasks, particularly peripheral ones, are forgotten or ignored.

More recently, Hartman, Hale and their associates[33-42] have developed a considerable body of research findings relating the effects of extended operations to the pilot's capability. As a result of their extensive research they have developed the concept of the physiological cost required of the aircrew to maintain a sustained level of performance. In their study of sustained operations, Hartman, Hale and Johnson[43] determined that this physiological cost was revealed by:

1. Relative hypothermia which has been described as a response to acute stress.

2. Increased subjective findings of fatigue.

3. Increased quantities of urinary catecholamines and 17-hydroxy corticosteroids.

Hartman, Hale and Johnson[43] have also observed massive changes in urinary by-products from long duration missions which were aborted due to crew fatigue. Johnson and Naitoh[14] have suggested that it would be interesting for future research to determine what portion of this physiological cost is due to the flight environment and what portion is due to sleep loss, since such dramatic changes in physiology have not been apparent in the nonflight research.

Billings[44] has also conducted research on the physiological cost of piloting a rotary wing aircraft. His results indicate that the metabolic cost of piloting a UH-1 in a hover is roughly equivalent to walking in place at 80 steps per minute. Billings has also investigated the effect of fatigue during several hours of flight. He found that there were substantial individual differences in performance resulting from this relatively short-term fatigue effect.

One study that addressed the actual operational consequences of sleep loss was conducted by Brictson[45] with his investigation of aircraft carrier landings. This research pointed out that changing or disrupting a pilot's routine or sleeping pattern resulted in the increased occurrence of landing errors.

In addition to the research which addresses the operational costs of sleep loss and fatigue to the pilot and the man-aircraft system, there is also a considerable quantity of research which focuses on establishing reasonable limits to flight time and crew rest for extended flight missions.[46-50]

A cohesive summary of conclusions applicable to the flight environment, resulting from the numerous investigations on sleep loss, sustained performance, and fatigue, are presented by Johnson and Naitoh.[14] These conclusions are:

1. The operational consequences of sleep loss and sleep deficit are difficult to determine with less than 60-72 hours of sleep loss.

2. The subjective attitude of the subjects is the primary factor affected by sleep loss.

3. There have been no studies that have conclusively demonstrated consistent performance decrements as a result of partial sleep loss, even though numerous illustrations of sleep disruption and sleep deficits have been developed.

4. A potentially useful alternative to the search for performance decrement is the concept of physiological cost; however, there is a need for more research on the long-term effects of the physiological changes and whether or not these changes are cumulative.

5. For future research, the "normal night minimum activation point," or diurnal low period, may serve as a useful reference point.

6. The circadian rhythm is a major factor in the influence of sleep loss.

7. The cumulative effect of duty hours during long duration missions may result in a logarithmic rise in the workload rather than a simple arithmetic increase.

The previous research investigations in the aviation environment, which have been only briefly described here, have produced several points of information which appear relevant to the development of flight mission guidelines:

1. This research produces evidence that the responsibilities and operating conditions of flying place <u>additional</u> demands upon crewmembers working within this environment.

2. The influence of the circadian rhythm and the disruptive effect of disturbing the sleep/wake cycle are again evident.

3. The presence of a fatigued state would appear to create a measurable difference in the pilot's skill or ability to process information and control the aircraft.

However, even though these points are relevant to specifying the effect of fatigue on operational performance, the conclusions are still too general to use as a basis for predicting the performance capability of the man-helicopter system across different levels of realistic operating constraints. Past aviation research has been accomplished using primarily fixed wing aircraft which are substantially different from rotary wing aircraft in operational characteristics, flight envelope and crew task requirements. Much of this research has only indirect application to realistic prediction of man-helicopter capability due to the limited goals of the individual research projects. These investigations focus on only one portion of the overall mission such as the carrier landing, or on the aftereffects of long duration missions, as with the concept of physiological cost.

The data obtained during the USAARL field investigation were designed to come to grips with the lack of specific information found in previous investigations through the direct measurement of both the man-helicopter system performance and "fatigue" measures obtained from a carefully designed battery of tests. Each of these measures had previously shown favorable relationships to fatigue related changes in pilot's abilities. The major analysis goal for this data was to provide information that could be directly applied to the rotary wing environment.

METHODS AND PROCEDURES

The USAARL field investigation examined six US Army pilots who each completed an extended 5-day flight schedule. During the in-flight portion of this investigation, direct measurement of the man-helicopter system performance was conducted. In addition, a battery of measures to include subjective rating scales, laboratory psychomotor tests and measurement of the aviator's physiological status was employed to identify which of the various tests were sensitive indicators of changes in the pilot's abilities and the man-helicopter system performance.

SUBJECTS

Subjects for this investigation were six US Army rotary wing aviators who had all recently completed the Initial Entry Rotary Wing (IERW) course conducted by the Army Aviation Center, Ft. Rucker, Alabama. Subjects, ranging in age from 23 to 26, were volunteers recruited from a graduating class. During the recruitment, the prospective subjects were informed that they would be participating in a fatigue investigation and that they would be required to fly a relatively large, but undefined, number of flight hours in a relatively short, but undefined, period of time. The prospect of obtaining many flight hours as the pilot-in-command was very appealing to these recent graduates since this category of flight time is an important determiner of seniority and is necessary in achieving aviation career goals.

A brief summary of the subjects' flight experience and qualifications is presented in Table 1. Five subjects were commissioned officers in the active Army. The remaining subject, a commissioned officer in a National Guard unit, had been placed on active duty for flight training. The first four subjects had received their training within the same flight class. The last two subjects graduated two weeks later.

INVESTIGATION SITE

The field investigation was conducted at the USAARL field research facility located at the Highfalls Stagefield approximately 20 miles south of Ft. Rucker in southeastern Alabama. This stagefield (Figure 1) is used exclusively for research and testing. Thus, there were no training conflicts.

Highfalls was used to provide a base of operations for the in-flight testing, research facilities for the laboratory and biochemical testing,

TABLE 1

SUBJECT PILOTS' AVIATION EXPERIENCE

Subject No.	Age	Total Hours	Instrument Flight	Night Flight	Highest Rating
		Rotary Wing Experience			
1	24	200	50	20	Commercial/ Instrument
2	25	204	51	20	Commercial/ Instrument
3	23	201	50	20	Commercial/ Instrument
4	26	225	50	24	Commercial/ Instrument
5	25	209	50	23	Commercial/ Instrument
6	25	206	50	20	Commercial/ Instrument
		Fixed Wing Experience			
1	24	80	10	3	Private
2	25	--	--	--	--
3	23	42	8	0	Private
4	26	--	--	--	--
5	25	39	5	0	Private
6	25	300	50	15	Commercial/ Instrument

and living quarters for the subjects and research personnel. Figure 2 shows an outside view of the facility.

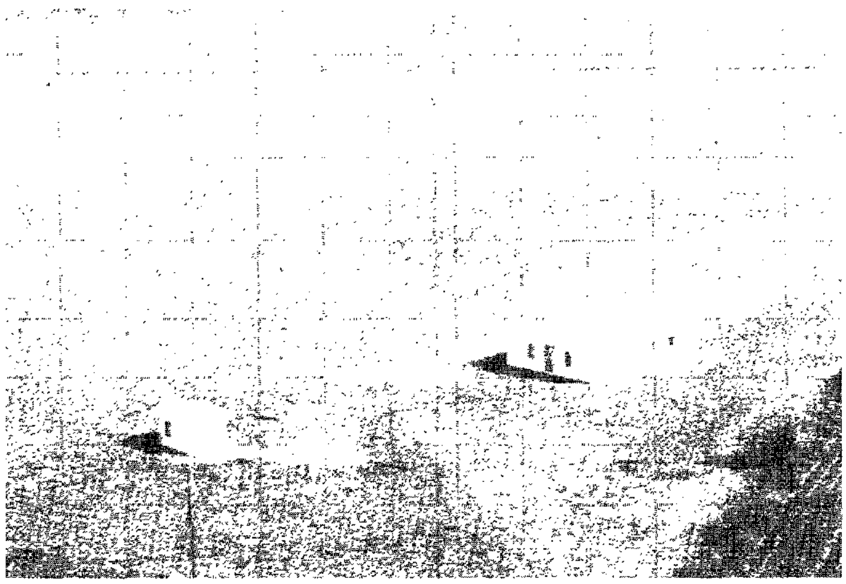

FIGURE 1. Aerial View of Highfalls Stagefield.

FIGURE 2. Outside View of Highfalls Research Facility.

RESEARCH PERSONNEL

The on-site research personnel for this investigation included:

1. Two primary investigators (a research psychologist and a biochemist).

2. Two in-flight investigators (an aviator/psychologist and a research psychologist).

3. One biochemical test supervisor.

4. Four laboratory technicians.

5. One JUH-1H crew chief.

6. Six safety pilots, each with an instructor pilot rating.

Other research personnel in the investigation included:

1. Two military flight surgeons.

2. One computer system analyst.

3. Three general support research assistants.

4. One refueling technician.

The primary investigators, the biochemical supervisor, and the crew chief remained at the research facility throughout the testing periods. During the flight testing portion of the investigation the in-flight investigators and the lab technicians split the day into two shifts of approximately 10 hours per shift. Safety pilots were scheduled in three shifts of approximately 6 hours per shift. The computer systems analyst processed the magnetically recorded data on a daily basis throughout the test period. Research assistants provided support during meals and other times as required.

AIRCRAFT

The in-flight portion of this investigation utilized three Army UH-1H helicopters. One of these aircraft was USAARL's JUH-1H research helicopter which was especially modified to provide information to the Helicopter In-Flight Monitoring System (HIMS). Two standard Army aircraft were obtained from the Fort Rucker Army Aviation Center fleet. The USAARL research aircraft and one of the Center fleet aircraft were used as research vehicles during the flight testing periods. The remaining aircraft was used as a reserve test vehicle and provided transportation to remote field sites for maintenance of the HIMS and peripheral equipment and transportation for personnel and biochemistry equipment.

Fuel for these aircraft was continuously available during the in-flight portion of the investigation. Daily maintenance was performed by the resident crew chief with more extensive maintenance performed between testing periods.

FIELD INVESTIGATION SCHEDULE

Field testing for this investigation was accomplished during three 2-week periods. During each of the investigation periods, subjects were transported to the test facility 48 hours before the start of flight testing. These 2 days were used to obtain baseline data on the physiological and biochemical measures and to familiarize the subjects with the laboratory tasks. The in-flight portion of the investigation started on the third day. A full schedule of experimental measurements (shown in Table 2) was continued for 5 days. The 8th, 9th, and 10th days of each investigation period were for subject recovery and to obtain post performance data. Subjects were released from the Highfalls test facility at the conclusion of testing on the 10th day. The remaining 4 days were used for experimenter rest, maintenance and preparation for the next session. Since the primary objective of the investigation was to observe the relationships between a battery of fatigue measures and in-flight performance, subjects were required to maintain a rigorous regimen of sleep/wake activity and diet.

On the first day of flight testing, subjects were awakened at 0430. Scheduled flights and experimentation continued until 0100 the following day (20.5 hours per day). Subjects were then allowed to sleep from 0100 until 0430 (3.5 hours). Meals were provided at 0615, 1215, and 1815. In addition, there was an established snack period at 2400. No snacks, other than noncaffeinic beverages, were allowed between the regularly scheduled eating periods. The consumption of alcoholic or caffeinic beverages was not allowed. Smoking was permitted during rest periods and a record of cigarette consumption was maintained.

During each flight period, each subject acted as aircraft commander (or first pilot) and was required to perform the maneuvers listed in Table 3. Subjects were allowed 50 minutes to complete as many of the standard maneuvers as possible. One subject flew the instrumented research helicopter while the second subject flew a standard Center fleet aircraft. At the end of each 50-minute flight profile, both subjects would return to the landing area, fill out subjective rating

TABLE 2

DAILY SCHEDULE OF EXPERIMENTAL MEASUREMENTS

TIME FRAME	SUBJECT ACTIVITIES	EXPERIMENTAL MEASURES								
		Flight HIMS	Urine	Blood	IP Rating	Pupilo-meter	DVA	Reaction Time	Mood Scale	Fatigue Rating
0100										
to	Sleep									
0430	Period		X							
0500		XX								
to										
0600	Flight	XX	X		X					
0615	Breakfast						X			
to	and									
0800	Testing			X		X	X	X	X	X
0800		XX								X
to										
0945	Flight	XX	X		X					X
1000		XX								X
to										
1145	Flight	XX	X		X					X
1200	Lunch						X			
to	and									
1400	Testing					X	X	X	X	X
1400		XX								X
to										
1545	Flight	XX	X		X					X
1600		XX								X
to										
1745	Flight	XX	X		X					X
1800	Supper			X		X	X			
to	and									
2000	Testing						X	X	X	X
2000		XX								X
to										
2145	Flight	XX	X		X					X
2200		XX								X
to										
2345	Flight	XX	X		X					X
2400	Snack						X			
to	and									
0100	Testing					X		X	X	X

TABLE 3

FLIGHT PROFILE STANDARD MANEUVERS

	Bad Weather	
1.	3 ft. Hover - 1 minute	(Measured)
2.	360° Pedal turn - left about mast	(Measured)
3.	360° Pedal turn - right about mast	(Measured)
4.	Slope - right skid	(Measured)
5.	Slope - left skid	(Measured)
6.	Hover taxi	(Measured)
7.	Lateral hover	
8.	360° Pedal turn - left about nose	
9.	360° Pedal turn - right about nose	
10.	360° Pedal turn - left about pilot	
11.	360° Pedal turn - right about pilot	
12.	360° Pedal turn - left about tail	
13.	360° Pedal turn - right about tail	
14.	Rearward hover	(Measured)
	Marginal Weather	
15.	10 ft. Hover - 1 minute	(Measured)
16.	25 ft. Hover - 1 minute	(Measured)
17.	50 ft. Hover - 1 minute	(Measured)
18.	Simulated max-gross takeoff	(Measured)
19.	Traffic pattern 300 ft. AGL	(Measured)
	Crosswind	(Measured)
	Downwind	(Measured)
	Base	(Measured)
	Final	(Measured)
20.	Shallow approach	(Measured)
	Good Weather	
21.	Normal traffic pattern	(Measured)
	Crosswind	(Measured)
	Downwind	(Measured)
	Base	(Measured)
	Final	(Measured)
22.	Normal approach	(Measured)
23.	Max performance takeoff	(Measured)
24.	Low level flight	(Measured)
	Heading	(Measured)
	Altitude	(Measured)
	Airspeed	(Measured)
25.	Confined area landing	(Measured)
26.	Max performance takeoff	(Measured)
	Heading	(Measured)
	Altitude maintenance	(Measured)
	Airspeed	(Measured)
27.	Shallow approach	(Measured)
	IFR (Hood)	
28.	Standard rate climbing turn left to 180°	
29.	Maintain straight and level flight 15 sec.	
30.	Standard rate descending turn right to 180°	
31.	Deceleration to 40 knots	
32.	Acceleration to 90 knots	

scales and rotate to the other aircraft. The initial assignment of the research helicopter was counterbalanced between subjects for each day. In this manner 2 hours of in-flight performance data were obtained from each subject for each 4-hour time block.

The maneuvers listed in Table 3 were selected to provide a realistic flight mission that could be accomplished over a wide range of weather conditions. Weather permitting, each maneuver was performed in the listed sequence. If the pilot accomplished all maneuvers during the test period, the profile was started again and as many maneuvers completed as time permitted. Both pilots performed the same sequence of maneuvers simultaneously. Subjects were instructed to perform each maneuver according to the US Army Flight School guidelines. During all flights, subjects were accompanied by a safety pilot who rated each maneuver. Decisions concerning modification of the maneuver sequence due to weather conditions or any emergency procedures were clearly understood to be the responsibility of the safety pilot. Those maneuvers that were selected to measure the effects of fatigue on in-flight performance are indicated in Table 3.

MEASUREMENT AND DATA ACQUISITION

The battery of measurements that were used to determine the level of the aviators' fatigue consisted of physiological and biochemical measurements, laboratory psychomotor tasks and subjective ratings of performance and fatigue. Throughout the in-flight portion of the investigation, objective measurements of the man-helicopter system performance were obtained using the Helicopter In-flight Monitoring System.

PHYSIOLOGICAL AND BIOCHEMICAL MEASUREMENT

Throughout the 10 days of investigation, during each of the three test periods, blood and urine samples were obtained from the subjects. Laboratory technicians obtained blood samples daily prior to the breakfast and supper eating periods, respectively. Serum and plasma samples were prepared, an analysis code was assigned and the samples were frozen at -60°C within 1 hour at the field research facility. The measures obtained from these analyses are presented in Table 4.

The total volume of urine from each of the subjects was collected throughout the investigation. The analysis of the urine samples was completed at Highfalls. The measures that were obtained from these analyses are also presented in Table 4.

Immediately upon awaking each day, EKG electrodes were applied to each subject. Continuous cardiovascular monitoring of the subjects was

TABLE 4

BIOCHEMICAL MEASURES USED IN EXAMINING AVIATOR FATIGUE

Urine Measures	
Initial pH	Cortisol
Lactic Acid	Epinephrine
Norepinephrine	Creatinine
Blood Measures	
Glucose	BUN (Blood Urea Nitrogen)
Creatine	Na (Sodium)
K (Potassium)	Cl (Chloride)
CO^2 (Carbon Dioxide)	Uric Acid
Ca (Calcium)	PO^4 (Phosphorus)
Iron	Total Protein
Albumin	Alkaline Phosphatase
Total Bilirubin	Cholesterol
TG (Triglyceride)	SGOT (Serum Glutamic Oxaloacetic Transaminase)
LDH (Lactate Dehydrogenase)	Cortisol
CPK (Creatine Phosphokinase)	

accomplished through the use of portable Avionics EKG tape recorders (Figure 3). The EKG records were transcribed using an Avionics Dynamic Electroscanner, Model 600, as shown in Figure 4.

Pupilometry measurements on each of the pilots were obtained four times a day during each testing/eating period and during the final testing period just prior to retiring. A Whittaker TV Pupilometer, Model 805 (Figure 5). was used to obtain these measures.

FIGURE 3. Portable Avionics EKG Recorder.

FIGURE 4. Avionics Dynamic Electroscanner, Model 600.

FIGURE 5. Whittaker Television Pupilometer.

LABORATORY PSYCHOMOTOR TASKS

Auditory reaction time measures were obtained during each of the four testing periods using a Lafayette, Model 63015, reaction time device. During each of the testing periods each subject completed 100 trials that were presented and scored by the research personnel. This apparatus is shown in Figure 6.

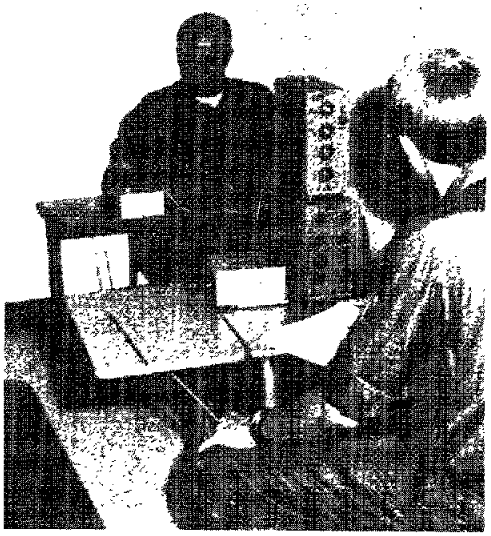

FIGURE 6. Auditory Reaction Time Apparatus

The dynamic visual acuity of each of the subjects was also tested during each of the four testing periods. A more complete description of this portion of the investigation can be found in USAARL Report No. 76-24.[7]

SUBJECTIVE RATING SCALES

During the in-flight portion of the fatigue investigation there were three sets of subjective rating scales used to assess changes in the pilots' feelings, attitudes and abilities: the post-flight performance scores provided by the subjects and by the safety pilots, and those subjective scores obtained during the testing/eating periods.

At the conclusion of each 50-minute flight period each of the subjects filled out the flight performance rating scale shown in Appendix

A-1. This is an adjective rating scale modeled after the Cooper-Harper rating scale.[51] In addition, the pilots completed an overall flight performance line rating scale (shown in Appendix A-2) and a fatigue intensity line scale (also shown in Appendix A-2).

During the execution of the established flight maneuver profile, the safety pilot graded each of the pilot's manuevers using a numerical scale from 1 to 10, with 10 representing outstanding performance. A sample of this rating scale is presented in Appendix A-3. In addition, at the conclusion of each flight period the safety pilot completed a flight performance rating scale (shown in Appendix A-1) identical to that filled out by the subjects.

During each of the testing/eating periods the subjects filled out additional subjective rating scales. These scales included a fatigue intensity line scale (identical to that found in Appendix A-2) and a feeling tone checklist (presented in Appendix A-4). The subjects also filled out a mood checklist questionnaire, which is shown in Appendix B.

ENVIRONMENTAL MEASUREMENTS

Since the flight environment may have substantial impact upon the obtained performance and fatigue scores, the weather records from Cairns Army Airfield, the nearest air weather station, were examined. From these records, measurements of the wind speed and direction and indications of the visibility were matched with each of the flight profiles. A record of those flights completed during darkness was also maintained.

IN-FLIGHT DATA MEASUREMENT AND DATA REDUCTION PROCESS

In-Flight Measurement

The Helicopter In-Flight Monitoring System (HIMS) (Figure 7) is a removable real-time electronic data gathering package designed to monitor 20 channels of information about an airborne helicopter to include pilot aircraft control inputs; aircraft attitude, rates, and accelerations in 6 degrees of freedom; and aircraft position over the ground.[52] The system is unobtrusive to the extent that the sensors are out of sight and do not alter the "feel" of the aircraft. The electronics and recording package is installed with the navigator on the floor behind the pilots' seats (Figure 8). There are no unusual aural or visual disturbances such as clicking relays, spinning wheels or flashing lights. At night, the already subdued lighting of the observers is further reduced by a blackout curtain hung between the pilot and observer stations.

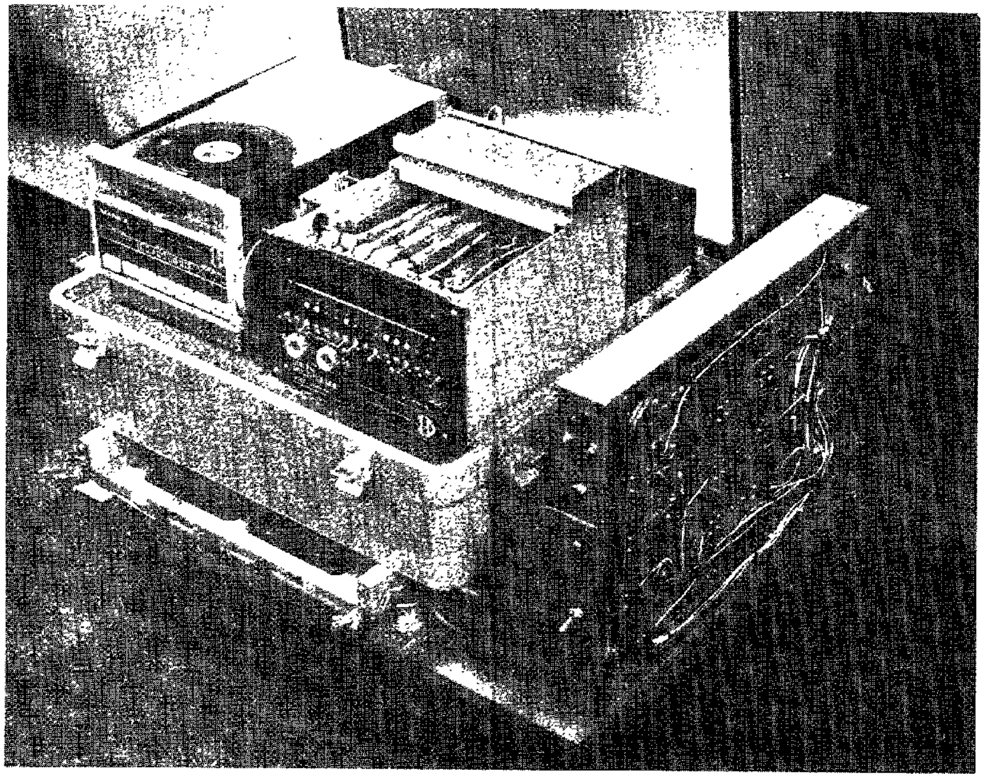

FIGURE 7. Helicopter In-Flight Monitoring System (HIMS).

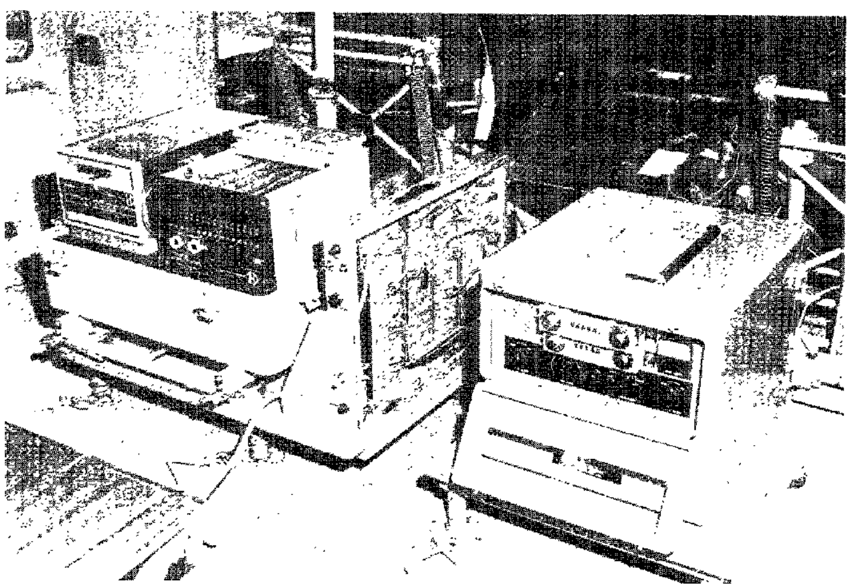

FIGURE 8. HIMS Installed in Research Aircraft.

As an overview (see Figure 9), the HIMS inputs are processed through a series of converters and multiplexers and are recorded on magnetic tape. In a subsequent set of processing steps, the data are converted back to values (called engineering units) which represent the appropriate real-world scales (inches, percent, degrees, etc.). It is this latter form that is used for the intermediate statistical analysis.

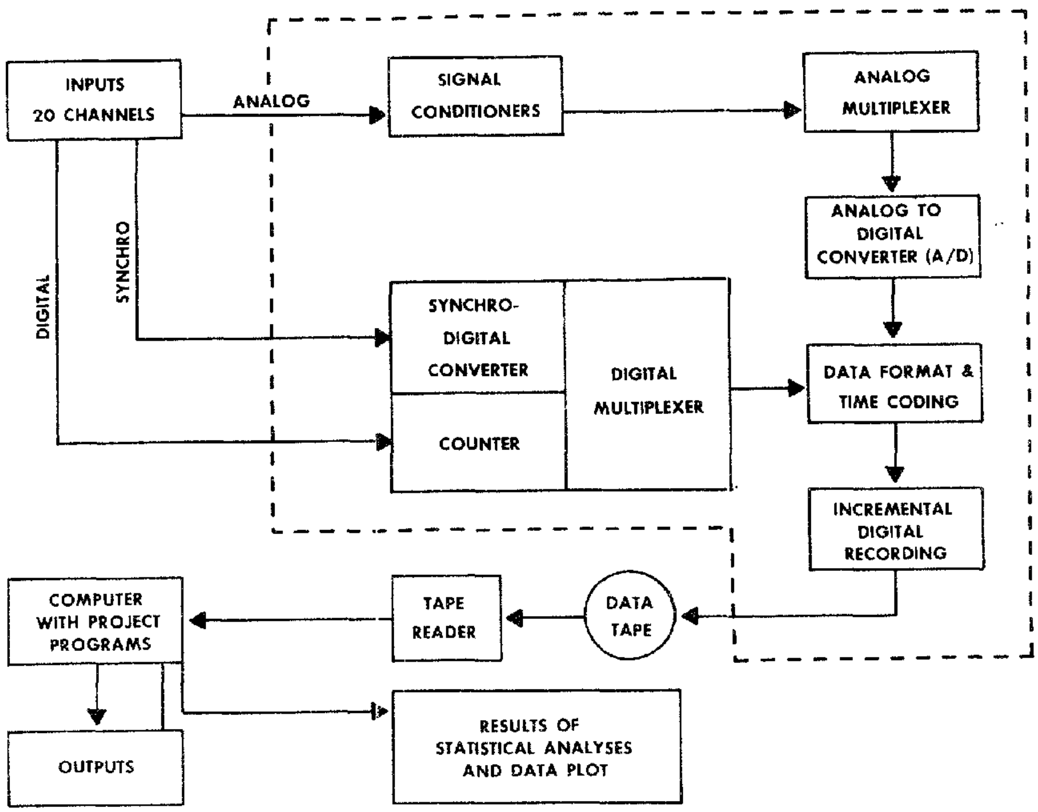

FIGURE 9. HIMS Data Flow Chart.

More specifically, each HIMS input source (see Figure 10) is connected to an appropriate device which converts its respective information to an equivalent electronic signal. Figure 11, for example, shows how the cyclic and pedal controls are connected to transducers under the floor panels of the helicopter. An incremental digital tape recorder within the system samples each of the input channels up to 20 times per second according to a preprogrammed formatter and records the data on a 7-track tape. The information shown in channels 4 and 5 of Figure 10 relates to the geographic position of the aircraft (within a prescribed

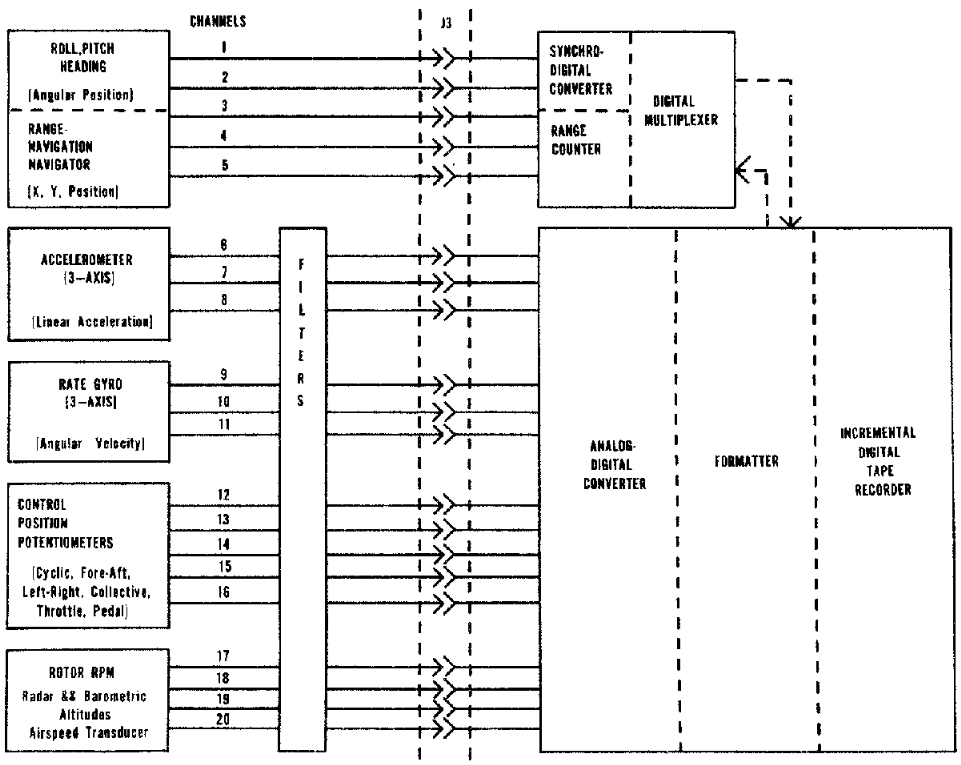

FIGURE 10. Functional Block Diagram.

area of approximately 125 square miles) as determined by an on-board navigator (Figure 12) linked to a ground-based radio ranging system.

In addition to the items shown in Figure 10, the time of day (or elapsed time since start, if not preset) is determined by an internal clock and recorded on the digital tape.

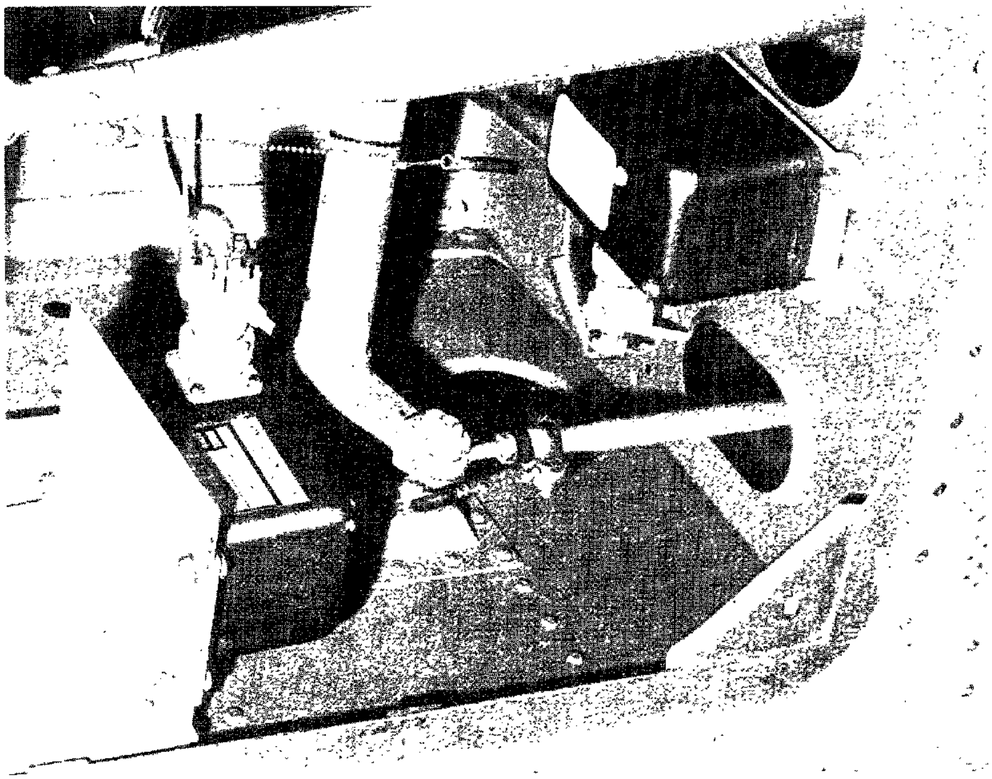

FIGURE 11. Flight Control Tubes Showing Connection to Transducers.

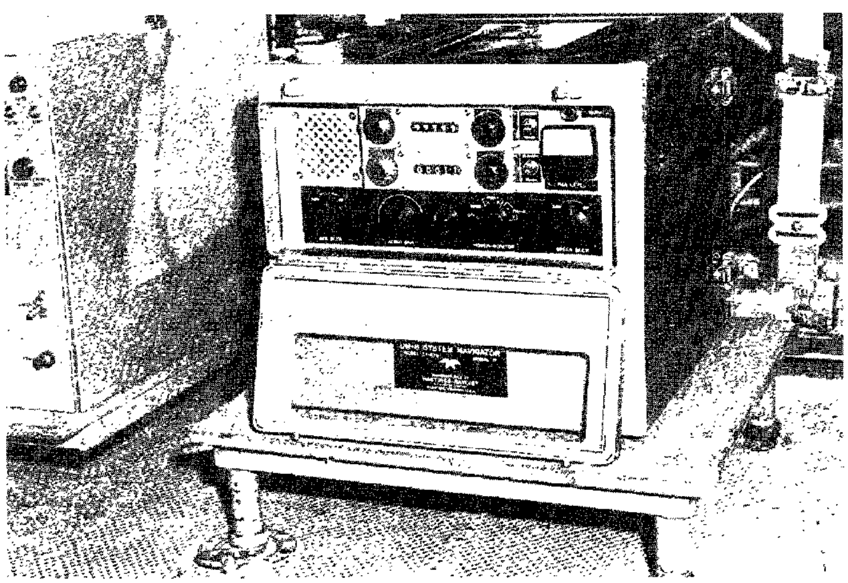

FIGURE 12. Ranging System Navigator On-Board Research Aircraft.

Data Reduction Process

HIMS data process begins at the aircraft before engine start time. Using auxiliary power (since the flight controls cannot be exercised in this aircraft with the engine running), the equipment is turned on and allowed to stabilize. Each channel is then "read" manually to verify its respective sensor and circuitry operation. Inputs that reflect the location, attitude and/or movement in space are examined in the static condition. These readings will be used later to calculate reference levels for each of the inputs. The metric for each of these is established by the manufacturer of the device.

The flight controls reflect the pilots' inputs to the aircraft and are measured (for calibration) at their respective extremes of physical movement. The reading at one of the extremes of each control becomes the reference level for that control; the difference between the two extremes is used to determine the metric. The voltage equivalents of all inputs are registered on a calibration sheet for use in the conversion phase.

As a first step in the conversion process, the calibration data are re-examined for validity. Electromechanical devices of the types used in HIMS are unavoidably subject to changes in temperature and/or pressure. These changes affect both the length of the bead chain connecting each control to its respective transducer (see Figure 11) and the electronic characteristics of the HIMS components themselves. Past experience with HIMS has established a range of values for each channel. Even though these effects are small, they are used to "adjust" the data so that subjects flown days, weeks or even years apart can be compared on a more accurate basis.

If the recorded calibration values are within limits, they are given to the computer program which sets up a conversion table unique to the particular flight. For each transducer (or other converter) a metric has been set up which will translate changes in voltage to real-world equivalents in terms of what are called engineering units (inches, percent, degrees, or whatever unit of measure is appropriate to the respective channel). The digital data are processed against that conversion table to produce a numerical reconstruction of the flight segment.

In the earlier days of HIMS, conversion of the digitally recorded flight data to a readable form required three runs on two computers because the HIMS generated tape was not compatible with any one computer system then available. The HIMS tape, being of a nearly continuous real-time 7-track format, had to be reformatted to a 9-track tape with interrecord gaps before it could be "read" by the conversion program.

Even the reference levels and metrics had to be calculated on a separate machine. Many days or weeks would pass before the investigator would see the results of the flight. Now, HIMS data are read directly into a disc storage area from the 7-track tape. The conversion program, having already set up the table, draws from the disc, performs the necessary calculations, and outputs the converted data to the line printer. Optionally, it may be stored on a 9-track tape until further analysis is required. The important element here is speed. The output is ready for review in less than 30 minutes. This means that the principal investigator can examine his data before the next flight, if that is required.

Figure 13 shows a page of converted data which might apply to a short-time segment of a flight. The header identifies the flight particulars (e.g., study, date, subject i.d., etc.); the columns are in engineering units appropriate to the respective channels; and at the bottom of the page is a summary of the extrema for each input in the time segment. These latter values play an important role in the review phase, next.

A typical HIMS (digital) tape holds about 30 minutes worth of data. Assuming that amount, there are 36,000 scans or 720,000 data points on the tape. It takes the computer about 12 minutes to process that much data without printing. The printout requires from 2 minutes to 3 hours depending upon the investigator's desired depth of examination. He must balance his need for accuracy against the time he has available to examine what the program will put out. Since the extrema (mentioned earlier) apply across all 36,000 scans regardless of the print frequency, printing one scan out of each 100 recorded saves time and is usually adequate for this level of review.

The initial examination is concerned with assurance that the flight data, as represented by the engineering units, constitutes a reasonable reflection of the actual flight segment. (Computer graphics are frequently used to reproduce a flight profile.) A comparison with the inflight observer's (usually copious) notes can reveal evidence of possible system malfunctions. Unchanging values, for instance, may indicate a broken connection or a damaged sensor. Very large changes, on the other hand, may indicate the passage of transient voltage spikes. The treatment of each is quite different and will be discussed in the next section.

Judgment is quite often a key factor in determining the start and stop times for a particular flight segment. Does a turn start when the command is given or when the pilot moves the controls or when the aircraft begins to turn? When does it stop? Regardless of the data in each channel, do all channels, taken as a whole, reflect the maneuver expected? Is there evidence of "bad" places in the data not printed? (Only 1% of the data is printed, but the extrema summary shows up all data points.)

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TIME HISTORY LISTING PAGE 117

STUDY 1 RUN 0 3 DATA 1 1/ 0 6/ 4 TEMP(C) 1 6 PRESSURE 0 7

PITCH	ROLL	HDNG	X	Y	AX	AY	AZ	ROL-R	PIT-R	YAW-R	CYCAF	CYCLR	COLL	THROT	PEDLR	RPM	ALTR	ALTB	A/S	MIN	SEC	DIST
3.5	1.2	317.4	9	0	0.03	-0.05	0.99	-1.0	1.8	3.3	-0.26	-0.72	4.64	97.9	-1.78	330.0	5.	230.	17.	9	38	9
3.7	-0.7	319.5	9	0	0.03	-0.05	0.96	1.1	1.5	4.3	-0.39	-0.70	4.66	97.9	-2.04	330.1	7.	224.	16.	9	39	9
3.5	0.7	321.8	9	0	0.04	-0.04	0.98	-0.4	2.0	3.2	-0.26	-0.90	4.70	97.7	-2.29	329.1	5.	224.	18.	9	40	9
3.7	-0.5	321.5	9	0	0.06	-0.02	0.99	-0.4	2.0	2.4	-0.28	-0.51	4.77	97.7	-2.24	329.1	5.	224.	17.	9	41	9
4.3	0.2	320.2	9	0	0.06	-0.06	0.99	-0.1	2.0	2.7	-0.51	-0.61	4.81	97.7	-1.94	330.0	5.	230.	18.	9	42	9
4.3	0.4	320.4	9	0	0.06	-0.04	0.97	-0.0	1.8	1.5	-0.57	-0.69	4.74	97.9	-2.12	330.0	7.	224.	18.	9	43	9
3.5	0.4	318.5	9	0	0.05	-0.05	0.96	0.6	1.2	0.2	-0.59	-0.51	4.67	97.7	-1.78	330.0	7.	224.	17.	9	44	9
2.8	0.9	316.9	9	0	0.06	-0.05	0.98	-0.8	2.3	1.6	-0.18	-0.67	4.68	97.7	-1.91	330.1	7.	230.	16.	9	45	9
3.7	-0.7	318.3	9	0	0.05	-0.07	0.98	-0.8	2.1	3.8	-0.52	-0.87	4.78	97.7	-2.31	329.1	7.	230.	15.	9	46	9
3.9	-0.4	319.2	9	0	0.05	-0.06	1.02	0.4	2.0	2.4	-0.46	-0.67	4.78	97.7	-2.14	328.7	10.	219.	15.	9	47	9
3.7	0.4	319.4	9	0	0.03	-0.05	1.00	-0.6	1.6	2.4	-0.54	-0.46	4.78	97.7	-2.18	330.0	7.	224.	16.	9	48	9
3.9	0.9	319.0	9	0	0.06	0.00	0.96	2.9	2.7	1.8	-0.62	-0.32	4.79	97.5	-2.00	330.0	7.	230.	16.	9	49	9
5.0	3.0	316.0	9	0	0.06	-0.03	0.98	-1.6	2.1	-0.4	-1.04	-0.35	4.86	97.9	-1.78	329.8	5.	224.	17.	9	50	9
3.7	-0.2	314.8	9	0	0.06	-0.05	0.98	-1.1	1.1	2.3	-0.52	-0.69	4.91	97.5	-2.07	330.0	7.	224.	16.	9	51	9
3.0	-0.4	315.7	12	0	0.06	-0.04	1.01	-0.4	1.5	2.5	-0.61	-0.69	4.91	97.9	-2.18	329.1	5.	224.	16.	9	52	12
2.8	-0.7	315.1	12	0	0.06	-0.06	1.00	1.5	1.9	1.1	-0.52	-0.60	4.77	97.7	-1.76	329.8	10.	230.	17.	9	53	12
3.2	-0.4	315.5	12	0	0.04	-0.05	0.98	-0.9	2.7	3.1	-0.44	-0.35	4.64	97.5	-2.01	330.8	5.	224.	16.	9	54	12
4.6	1.2	316.5	12	0	0.06	-0.06	0.97	1.1	2.0	3.3	-0.87	-0.43	4.68	97.9	-1.92	329.8	10.	224.	15.	9	55	12
4.1	0.2	316.4	12	0	0.06	-0.05	0.97	-2.0	1.7	1.5	-0.61	-0.63	4.80	97.5	-1.95	328.7	10.	230.	16.	9	56	12
3.5	-0.4	316.0	12	0	0.02	-0.06	0.97	-0.0	2.3	3.0	-0.34	-0.54	4.78	97.7	-2.05	329.8	7.	224.	16.	9	57	12
4.1	-0.7	316.9	12	0	0.05	-0.06	0.98	-0.7	1.8	3.1	-0.51	-0.60	4.78	97.7	-2.06	330.1	7.	224.	16.	9	58	12
4.3	-0.7	317.6	12	0	0.06	-0.06	0.96	0.9	1.6	2.8	-0.49	-0.35	4.71	97.9	-2.07	330.1	10.	230.	16.	9	59	12
4.1	0.9	317.3	9	0	0.05	-0.05	1.00	0.3	2.4	1.6	-0.66	-0.63	4.72	97.9	-1.96	329.6	10.	230.	16.	10	0	16
4.6	-1.3	315.7	9	0	0.06	-0.05	0.97	-0.7	1.9	1.3	-0.77	-0.43	4.72	97.5	-1.93	330.3	7.	224.	16.	10	1	16
4.3	-0.2	314.4	9	0	0.06	-0.05	0.99	-0.3	1.5	2.0	-0.64	-0.57	4.79	97.7	-1.85	330.1	7.	224.	17.	10	2	16
5.2	-1.4	314.1	9	0	0.05	-0.08	0.98	-0.0	1.3	1.0	-0.51	-0.51	4.78	97.7	-1.88	329.6	10.	224.	17.	10	3	16
2.6	0.2	312.7	9	0	0.03	-0.06	0.97	1.0	2.3	1.3	-0.41	-0.46	4.78	97.5	-1.78	329.8	7.	224.	16.	10	4	16
4.1	0.7	311.8	9	0	0.06	-0.05	0.98	-0.7	2.8	2.5	-0.76	-0.31	4.76	97.9	-1.73	330.8	10.	224.	16.	10	5	16
4.1	-0.4	312.5	9	0	0.06	-0.06	0.95	0.1	1.5	2.8	-0.51	-0.58	4.75	97.7	-1.91	330.4	5.	224.	16.	10	6	16
3.5	0.7	313.0	12	0	0.06	-0.06	0.98	-0.9	1.9	1.1	-0.39	-0.58	4.76	97.7	-1.80	329.6	5.	230.	16.	10	7	19
3.9	-1.3	311.8	12	0	0.06	-0.09	0.98	-1.0	1.9	2.5	-0.61	-0.43	4.75	97.7	-1.58	330.4	7.	230.	17.	10	8	19
3.9	-0.7	313.7	12	0	0.04	-0.05	0.98	-0.3	1.8	4.6	-0.52	-0.51	4.74	97.7	-1.83	330.4	10.	224.	17.	10	9	19
3.7	0.2	315.0	12	0	0.05	-0.05	0.98	1.6	1.8	2.4	-0.36	-0.54	4.74	97.7	-1.80	329.8	12.	230.	17.	10	10	19
4.3	-0.2	314.8	12	0	0.04	-0.06	0.95	-1.2	1.6	3.1	-0.82	-0.47	4.74	97.7	-1.80	330.3	10.	219.	17.	10	11	19
3.5	0.2	316.0	12	0	0.06	-0.05	0.96	0.8	1.8	2.9	-0.52	-0.46	4.64	97.5	-1.88	330.3	10.	224.	16.	10	12	19
3.5	0.5	315.7	12	0	0.05	-0.06	0.96	0.8	1.8	1.5	-0.49	-0.64	4.64	97.7	-1.76	330.0	10.	230.	15.	10	13	19
2.8	0.5	312.7	12	0	0.06	-0.05	0.98	-2.2	1.9	0.6	-0.34	-0.72	4.66	97.7	-1.61	330.3	7.	219.	16.	10	14	19
3.3	-1.4	311.6	12	0	0.04	-0.06	0.97	-0.2	2.4	3.1	-0.61	-0.60	4.65	97.9	-1.59	330.9	7.	219.	16.	10	15	19
3.7	-2.0	313.2	12	0	0.06	-0.06	0.98	0.1	1.6	2.4	-0.41	-0.57	4.66	97.7	-1.65	330.4	7.	224.	16.	10	16	19
3.5	0.5	313.4	12	0	0.04	-0.06	0.96	2.1	1.6	3.1	-0.31	-0.47	4.65	97.5	-1.60	330.4	10.	230.	16.	10	17	19
3.5	0.7	313.9	12	0	0.03	-0.04	1.02	0.4	2.3	2.6	-0.39	-0.47	4.70	97.9	-1.64	330.1	10.	224.	17.	10	18	19
4.3	0.7	314.1	12	0	0.06	-0.05	0.98	-0.7	2.1	2.6	-0.66	-0.46	4.75	97.5	-1.63	330.1	7.	224.	16.	10	19	19
3.7	0.4	315.5	12	0	0.06	-0.05	1.00	-1.1	1.2	3.8	-0.36	-0.67	4.73	97.5	-1.77	330.4	7.	230.	16.	10	20	19
3.5	-0.5	317.1	12	0	0.06	-0.05	0.96	0.2	2.2	2.8	-0.56	-0.66	4.57	97.7	-1.83	330.6	10.	224.	16.	10	21	19
3.3	0.9	317.3	18	0	0.05	-0.05	0.97	-0.2	1.7	2.4	-0.37	-0.66	4.59	97.7	-1.70	330.8	7.	224.	16.	10	22	25
3.7	-0.2	316.7	18	0	0.06	-0.06	0.97	0.5	2.5	2.0	-0.52	-0.57	4.59	97.9	-1.70	330.6	10.	224.	17.	10	23	25
3.7	0.9	316.5	18	0	0.06	-0.05	0.98	-0.9	1.4	2.2	-0.56	-0.58	4.60	97.9	-1.84	330.4	10.	230.	16.	10	24	25
3.0	-0.0	315.8	18	0	0.06	-0.06	0.98	-1.1	2.0	1.7	-0.14	-0.73	4.60	97.7	-1.80	330.0	10.	224.	17.	10	25	25
3.7	-0.7	314.6	18	0	0.06	-0.04	0.98	0.9	2.4	1.3	-0.46	-0.41	4.72	97.7	-1.66	330.0	5.	224.	16.	10	26	25
4.6	1.6	313.7	18	0	0.06	-0.06	0.97	0.2	2.5	2.6	-0.72	-0.58	4.69	97.7	-1.68	330.4	5.	224.	16.	10	27	25
4.3	-0.7	314.1	18	0	0.06	-0.06	1.00	-0.7	1.5	2.6	-0.31	-0.61	4.60	97.5	-1.69	330.3	5.	224.	16.	10	28	25
3.7	-0.0	314.1	18	0	0.05	-0.06	0.96	0.3	1.6	2.9	-0.29	-0.61	4.56	97.9	-1.70	330.9	7.	224.	17.	10	29	25
3.5	-0.4	315.1	18	0	0.05	-0.02	0.95	-0.6	1.8	2.5	-0.61	-0.51	4.58	97.7	-1.75	330.3	2.	224.	17.	10	30	25
3.3	-0.2	315.8	18	0	0.06	-0.06	0.96	1.0	2.0	2.9	-0.51	-0.47	4.57	97.5	-1.75	330.4	7.	230.	16.	10	31	25
3.5	1.6	317.6	18	0	0.06	-0.05	0.99	-0.5	2.1	3.9	-0.46	-0.60	4.72	97.5	-1.90	330.0	7.	219.	16.	10	32	25

FIGURE 13. Sample of HIMS Data Printout.

If the data are acceptable to the investigator, he must isolate the segments in terms of time (to the nearest whole second) and resubmit the data to obtain intermediate statistics.

The intermediate statistics program (HIMSTAT) is a multifunction program used not only to calculate the statistics themselves, but to "prepare" the data for analysis as well. Each data point is first screened against a logical data limit that acts as a filter for transient voltages that may get past the HIMS filters. For example, a data point showing a collective position of 10.6 inches (the maximum upper limit) is probably in error, since it is highly unlikely that a pilot would reach such an extreme in a standard maneuver. The data points on either side of the "offender" are also examined. If the point is significantly larger than the mean of the adjacent points, it is replaced by that mean.

The program also enables the user to plot raw data from any selected channel and to display the plot on a choice of graphics. This option has proven to be extremely useful in allowing the investigator to review large amounts of data in a relatively short period of time. It also allows the trends of data to be observed.

After the data are "cleaned," they are used to calculate the intermediate statistics. There are basically two avenues of approach to these conditions--one involves the sequential examination of the position of each control, the other involves channel information other than flight control inputs. Table 5 is a list of the flight parameters measured and those derived from the data. Table 6 is a list of the intermediate statistics calculated. Table 7 is a list of definitions for the control measures. The control <u>position</u> data recorded on the HIMS tape requires some special handling to obtain the control <u>movement</u> data.

CONTROL MOVEMENT PROCESSING

A two-parameter algorithm was developed for computer processing of position data for the cyclic fore-aft, cyclic left-right, pedal, collective and throttle controls. Through this algorithm, periodic measurements of the position of the pilot's control may be examined in order to identify and characterize meaningful control inputs by the pilot. With the proper choice of parameters, this algorithm reliably detects control movements and measures their magnitudes and average rates of change. Information from all the detected movements are accumulated to determine the frequency of control movements and reversals, plus maximum, minimum, mean and standard deviation values for control movement amplitudes and rates.

TABLE 5

PARAMETERS MEASURED AND DERIVED MEASURES

Parameters Measured (Statistics*)	Derived Measures (Statistics*)
1. Pitch (1-6)**	Pitch Rate (1,2,6)
2. Roll (1-6)	Roll Rate (1,2,6)
3. Heading (1-6)	Rate of Turn (1-6)
4. Position X	
5. Position Y (3,4,5)	Ground Speed (1-5)
6. Acceleration X (6)	
7. Acceleration Y (6)	
8. Acceleration Z (6)	
9. Roll Rate (6)	Roll Acceleration (6)
10. Pitch Rate (6)	Pitch Acceleration (6)
11. Yaw Rate (6) Z	Yaw Acceleration (6)
18. Radar Altitude (1-6)	Rate of Climb (1-6)
19. Barometric Altitude (1-6)	Rate of Climb (1-6)
20. Airspeed (1-6)	
21. Flight Time	
17. Rotor RPM (6)	
15. Throttle (6)	
12. Cyclic Stick (Fore-Aft) 13. Cyclic Stick (Left-Right) 14. Collective 16. Pedals	Control Position (1,2,6), Absolute Control Movement Magnitude (1,2,6), Positive Control Movement Magnitude (1,2,6), Negative Control Movement Magnitude (1,2,6), Absolute Average Control Movement Rate (1,2,6), Average Positive Control Movement Rate (1,2,6), Average Negative Control Movement Rate (1,2,6), Control Reversals (7), Instantaneous Control Reversals (7), Control Steady State (7-10), Control Movement (8,9)***

*See Table 6
**Numbers 1-21 Indicate HIMS Printout Columns
***See Table 7

TABLE 6

INTERMEDIATE STATISTICS

1.	Mean	$\bar{x} = \sum \frac{x_i}{n}$
2.	Standard Deviation	$\sqrt{\frac{\sum x^2_i}{n} - \bar{x}^2}$
3.	Average Constant Error	$\frac{\sum (x_i - x_o)}{n}$
4.	Average Absolute Error	$\frac{\sum \lvert x_i - x_o \rvert}{n}$
5.	Root Mean Square Error	$\sqrt{\frac{\sum (x_i - x_o)^2}{n}}$
6.	Maximum and Minimum Values	
7.	Number of Occurrences	
8.	Total Time in Condition	
9.	Percent of Total Flight Time in Condition	
10.	Mean Duration Time	

x_0 in 3, 4, and 5 are Selectable Input Values

TABLE 7

CONTROL MEASURES

1. Control Movement - A change in the position of a control over several consecutive readings in one direction.

2. Control Steady State - The period during which the actual control movement and rate of movement are less than predetermined input values.

3. Control Reversal - A change in the direction of movement of a control outside of steady state periods.

4. Instantaneous Control Reversal - A change of control movement direction as computed for consecutive samples.

5. Control Movement Magnitude - $\Delta x = x_{t2} - x_{t1}$

6. Average Control Movement Rate - $\dfrac{\Delta x}{\Delta t} = \dfrac{x_{t2} - x_{t1}}{t2 - t1}$

7. Instantaneous Control Rate - The derivative obtained from a fourth degree equation fitted through five consecutive samples with the desired time at the middle point.

Therefore,

$$\frac{dxt3}{dt} = \frac{20}{12} [x_{t1} - x_{t5} - 8 (x_{t2} - x_{t4})]$$

The detailed operation of the algorithm is described using Figure 14 which shows a hypothetical segment of noise control position data.

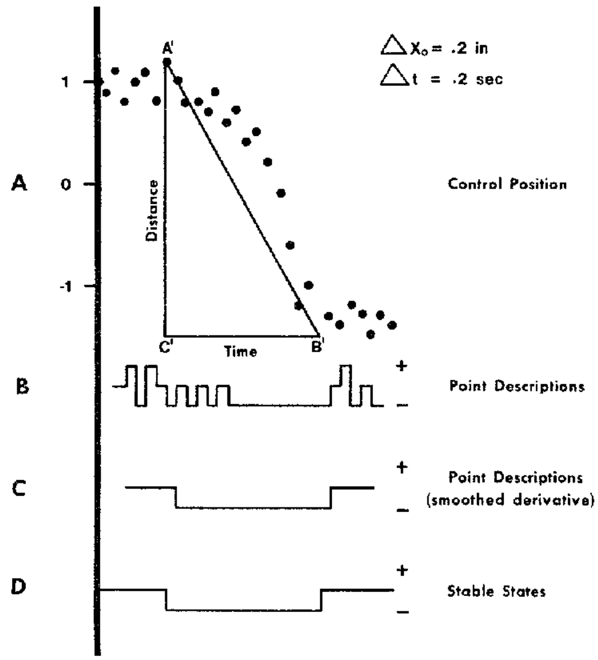

FIGURE 14. Plots of Hypothetical Data.

The dots on the curve represent digital samples taken at precisely 50ms intervals by the HIMS. Each point on the data curve can be described as increasing, decreasing or steady with respect to the preceding point. The appropriate trend is determined by comparing the change, dx, in the control position over a time, dt, which is centered at that point. The point is described as increasing if $dx>dx_0$, decreasing if $dx<dx_0$, and steady if $-dx_0<dx<dx_0$. The two parameters, dx_0 and dt, are chosen so that the magnitude of the ratio dx_0/dt is the smallest slope which describes a section of the data curve which is changing. In addition, dt must be a time long enough for noise fluctuations to "average out," but not long enough to span an entire control movement. If the point description is the same for consecutive data points covering a time span greater than dt, then the control is said to have entered a stable state, which can be either an increase, decrease or steady state. The beginning of that stable state is defined to be the data point which is furthest from the center of the nearest movement, but has the same point description as the movement.

In the example in Figure 14, the dx_0 parameter is .2 inches and the dt parameter is .2 seconds so that changes of 2 divisions or more in the control position between data points are separated in time by 4 divisions. The point descriptions for this data curve are shown at diagram B of Figure 14 where a step above the axis represents an increase. A step below the axis represents a decrease and a step along the axis represents a steady condition. With low noise data the diagram at B would show two transitions--one at the beginning of the movement from steady to decreasing, and one at the end of the movement back to steady. When noise is present, the determination of the point descriptions can be made more reliable by smoothing the derivative, or dx. It is adequate to replace each dx by the average of itself and its two neighbors. The result of such averaging for this example is shown in diagram C. The next step is to search through the data within dt/2 (two divisions, in this case) of the transition points in diagram C for the point furthest from the center of the nearest movement. For a downward movement such as in Figure 14, this point would be maximum at the beginning of the movement and a minimum at the end. The points so determined for Figure 14 are the transition points in diagram D which locate the position and time coordinates of the beginning and end of the pilot's control input on the data curve. The triangle in diagram A has vertices at the starting and ending points of the movement, A' and B', respectively. The length of line A'C' is the duration of the movement, and the ratio of these two lengths is the average rate of change over the movement. Statistics for the nonflight-control input data are straightforward. The output for all data is put on a 9-track tape for more indepth analysis at a later time.

SUMMARY OF CURRENT STATUS

As was stated in the introduction of this report, the overall goal of the USAARL fatigue investigation was to provide the flight commander with the information he requires in making mission judgments. This ongoing research program is designed to accomplish this goal in two ways: first, through the identification of critical periods during extended missions where detrimental changes in aircrew performance may be observed; and second, through the development of a practical measure of aircrew fatigue that may be used in the operational environment. The previous section clearly shows the tremendous magnitude of information that is generated when only the measures of in-flight man-helicopter system performance are considered, and outlines the sophisticated processing and bookkeeping procedures that are required to transform this data into usable information. In addition, there are many other measures from the battery of potential fatigue indicators including the subjective rating scores, the biochemical and physiological measures and the scores from the laboratory psychomotor tests. The research personnel who are continuing to process and analyze this vast data array are methodically working through all of the relevant measures for each channel for each of the flight maneuvers. From a methodological viewpoint, the need is for a simple system description that will allow a practical statement about the probable effect of a given amount of aircrew fatigue upon a specific type of aviation mission. The measures obtained from both the pilot and the aircraft are being carefully examined to relate them to the fatigue indicators.

At the current time most of the information from all aspects of this investigation are in a form that makes comparison possible. The research methods that are applied to this data during analysis and description are highly developed and under continuous improvement. The data that has been obtained and will be collected as a function of the USAARL fatigue research program will provide relevant and timely information to the local flight commander and will be instrumental in establishing a comprehensive data base that will provide solutions for future aircrew fatigue problems.

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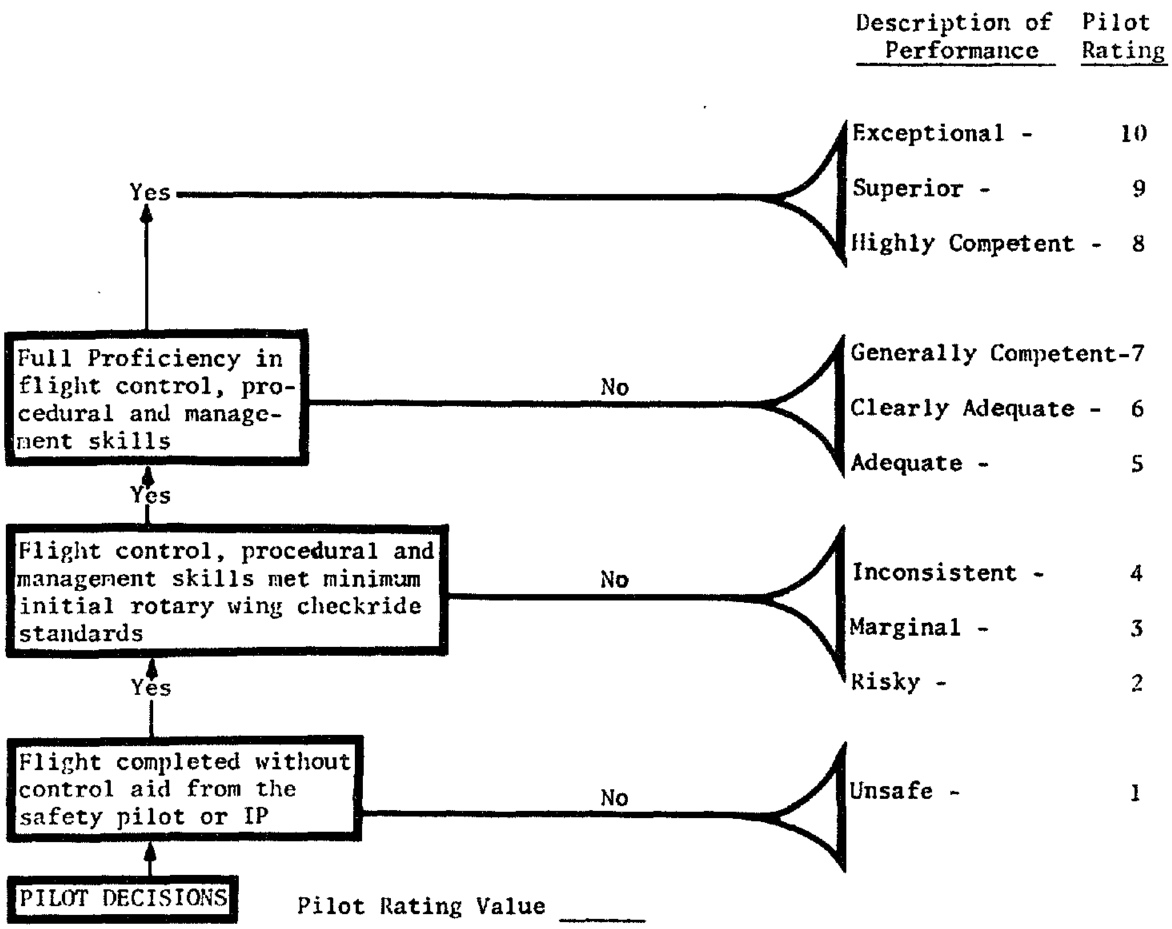
APPENDIX A

CHECKLISTS AND RATINGS ADMINISTERED TO FLIGHT PERSONNEL

FLIGHT PERFORMANCE RATING SCALE
(Completed by Both the Subject and Safety Pilot)



OVERALL FLIGHT PERFORMANCE RATING SHEET
(Subject Rating)

Place a checkmark on the line above to indicate your evaluation of your overall flight performance during the preceding flight session.

FATIGUE INTENSITY SCALE

Place a checkmark on the line above to indicate the degree of fatigue intensity you feel at this moment.

SAFETY PILOTS' RATING SHEET

IP (Bad Wx)		GRADE
1. Hover to Zero Point & Land		12345678910
2. 3 ft Hover - 1 minute - Land	R	12345678910
3. 3 ft Hover - 360° Pedal Turn Left Stabilize 20 sec	R	12345678910
4. 360° Pedal Turn Right (20 sec pause)	R	12345678910
5. Hover to Slope Area (pause 10 sec)		12345678910
6. Slope Lndg-Right Skid Up-180° Turn	R	12345678910
7. Slope Lndg-Left Skid Up-Hover Back to Zero Point	R	12345678910
8. Hover Perimeter of Runway	R	12345678910
9. Lateral Hover (Rq Left)		12345678910
10. Lateral Hover (Back to Zero)		12345678910
11. 360° Right Turn (Nose Pivot Point)		12345678910
12. 360° Left Turn (Nose Pivot Point)		12345678910
13. 360° Right Turn (Tail Pivot Point)		12345678910
14. 360° Left Turn (Tail Pivot Point)		12345678910
15. Forward Hover Runway (Stop)		12345678910
16. Rearward Hover Runway (Stop) Land (MARGINAL WX)	R	12345678910
17. 10 ft Hover - 1 min (Land)	R	12345678910
18. 25 ft Hover - 1 min (Land)	R	12345678910
19. 50 ft Hover - 1 min (Land) (BAD WX)	R	12345678910
20. Max Performance T/O (Traffic 1000' ind)	R	12345678910
Takeoff	R	12345678910
Crosswind	R	12345678910
Downwind	R	12345678910
Base	R	12345678910
Final	R	12345678910
21. Steep Approach to Touchdown at Zero Point	R	12345678910
22. Normal Takeoff from Ground	R	12345678910
Crosswind	R	12345678910
Downwind	R	12345678910
Base	R	12345678910
Final	R	12345678910
23. Normal Approach to Touchdown	R	12345678910
24. Minimum Power Takeoff	R	12345678910
25. Low Level Flight to Confined Area (A/S 80) (Alt - 400 day; 500 night) (Head 300°)	R	12345678910
26. Confined Area Landing (Day Only)	R	12345678910
27. Confined Area Takeoff and Low Level Back to Field (A/S 60) (Alt-400 day; 500 night) (Hdg 120°)	R	12345678910
28. Modified Pattern (Shallow Approach to Touchdown)	R	12345678910
29. ITO - Climb to 1000' and Hdg 180° (Stabilize 1 min)		12345678910
30. Standard Rate Climbing Right Turn to 1500' and Hdg 360° (Stabilize 1 min)		12345678910
31. Standard Rate Descending Left Turn to 1000' and Hdg 180° (Stabilize 1 min)		12345678910
32. Deceleration to 40 Knots		12345678910
33. Accelerate to 90 Knots		12345678910
34. IP Issues GCA Back to Highfalls; Take & Land A/C on Short Final		12345678910

FEELING TONE CHECKLIST

We would like to find out how you feel right now. Below you will see 10 statements which describe different degrees of freshness or peppiness and tiredness. For each statement you will have to determine whether you feel at this time (1) "better than," (2) "same as," or (3) "worse than" the feeling described by that statement. Having done this you will place an "X" in the appropriate box. Consider the following example:

	Better Than	Same As	Worse Than	Statement
1.	( )	( )	(XX)	Extremely fresh
2.	( )	(XX)	( )	Slightly tired
3.	(XX)	( )	( )	Completely exhausted

In other words, this person feels worse than "extremely fresh," about the same as "slightly tired," but, on the other hand, better than "completely exhausted."

Now, answer each of the following statements as follows:

If you feel better than the statement, place an "X" in the "better than" column.

If you feel about the same as the statement, place an "X" in the "same as" column.

If you feel worse than the statement, place an "X" in the "worse than" column.

Remember, answer each question with regard to how you feel at this instant.

	Better Than	Same As	Worse Than	Statement
1.	( )	(XX)	( )	Very lively
2.	(XX)	( )	( )	Extremely tired
3.	( )	(XX)	( )	Quite fresh
4.	(XX)	( )	( )	Slightly pooped
5.	( )	( )	(XX)	Extremely peppy
6.	( )	(XX)	( )	Somewhat fresh
7.	(XX)	( )	( )	Petered out
8.	( )	( )	(XX)	Very refreshed
9.	(XX)	( )	( )	Fairly well pooped
10.	(XX)	( )	( )	Ready to drop

APPENDIX B

MOOD CHECKLIST QUESTIONNAIRE

NAME________________________

DATE______________TIME________

TEST NO.______________________

MOOD CHECKLIST

INSTRUCTIONS

On the following pages you will find lists of words describing different kinds of moods and feelings. Indicate how each word is characteristic of how you feel AT THIS MOMENT by placing a 1, 2 or 3 in the blank after each word.

1 = Not at All

2 = Somewhat or Slightly

3 = Mostly or Generally

PAGE ORDER________

1 = Not at All

2 = Somewhat or Slightly

3 = Mostly or Generally

GOOD	____
CONTENTED	____
ANNOYED	____
SAD	____
INACTIVE	____
ALARMED	____
LIGHTHEARTED	____
IMPATIENT	____
GRIEF-STRICKEN	____
DESPAIRING	____
UNEASY	____
OVERJOYED	____
TERRIFIED	____

1

1 = Not at All

2 = Somewhat or Slightly

3 = Mostly or Generally

INSECURE	____
FINE	____
LAZY	____
BURNED UP	____
PLEASED	____
CHEERFUL	____
ENERGETIC	____
DOWNCAST	____
SCARED STIFF	____
SARCASTIC	____
ON TOP OF THE WORLD	____
SATISFIED	____
HOPELESS	____

1 = Not at All

2 = Somewhat or Slightly

3 = Mostly or Generally

LIVELY	____
REFRESHED	____
JITTERY	____
LEISURELY	____
LOW	____
ALERT	____
FEARFUL	____
GROUCHY	____
ANGRY	____
RESTLESS	____
STEADY	____
LONELY	____
APPREHENSIVE	____

3

1 = Not at All

2 = Somewhat or Slightly

3 = Mostly or Generally

RAGING	____
TIMID	____
MAD	____
DEPRESSED	____
BLUE	____
WEARY	____
DESPERATE	____
AFRAID	____
INDIGNANT	____
HOPPING MAD	____
QUIET	____
HAPPY	____
MISERABLE	____
BOILING MAD	____

4

1 = Not at All

2 = Somewhat or Slightly

3 = Mostly or Generally

PANICKY	____
DROWSY	____
MEAN	____
ACTIVE	____
SLUGGISH	____
IRRITATED	____
HOSTILE	____

1 = Not at All

2 = Somewhat or Slightly

3 = Mostly or Generally

JOYFUL	____
WONDERFUL	____
VIGOROUS	____
INDIFFERENT	____
CALM	____
SORROWFUL	____
SOLEMN	____